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From micro-cantilever testing to deformation patterning in HCP polycrystals

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[1] Anisotropy in the plastic flow properties of single crystal alpha Ti determined from micro cantilever beams J Gong and AJ Wilkinson, Acta Materialia, (2009), 57, 5693-5705 [2] A microcantilever investigation of size effect, solid-solution strengthening and second-phase strengthening for prism slip in alpha-Ti, J Gong and, AJ Wilkinson, Acta Materialia, (2011), 59, 5970-5981 [3] A discrete dislocation plasticity study of the micro-cantilever size effect E Tarleton, DS Balint, J Gong, and AJ Wilkinson, Acta Materialia (2015) 88, 271-282 [4] Transmission electron microscopy of deformed Ti–6Al–4 V micro-cantilevers R Ding, J Gong, AJ Wilkinson and IP Jones, Philosophical Magazine, (2012), 92, 3290–3314 [5] Dislocations in deformed Ti–6Al–4V micro-cantilevers R Ding, J Gong, AJ Wilkinson, IP Jones, Acta Materialia (2014) 76 127-134 [6] prismatic, basal, and slip strengths of commercially pure Zr by micro-cantilever tests J Gong, TB Britton, M Cuddihy, FPE Dunne and AJ Wilkinson (2015), under review

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FROM MICRO-CANTILEVER TESTING TO DEFORMATION PATTERNING IN HCP POLYCRYSTALS

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For several years now we have been using micro-scale cantilever bend tests to probe the considerable anisotropy of elastic and plastic deformation behaviour in the hexagonal packed metals Ti and Zr [1-3]. The wider aim of the work has been understanding and modeling the heterogeneous patterns of stress, strain and dislocation density that develop during deformation of HCP polycrystals. Crystal plasticity finite element analysis (CP-FEA) of representative volumes are used to simulate these deformation fields and enable modelling of representative volume elements to aid understanding of in-service component performance. Critical resolved shear stress (CRSS) values for the important slip systems are required inputs for the constitutive laws and populating these has been the aim of our micro-cantilever studies.

We follow a well-established route of using a focused ion beam (FIB) to machine micro-cantilevers of triangular cross-section into the sample surface [1]. EBSD is used to identify grains in which cantilevers with suitable orientation can be cut so that the targeted slip systems can be activated individually. The samples are then passed to a nano-indenter with a nano-positioning stage and loaded, with the load point accurately located at the free end of the cantilever using an AFM-like scan with low contact force. Load-displacement data generated from the experiment are compared to CP-FEA simulations of the cantilever bending and the CRSS for each cantilever is varied until a good fit is achieved [1].

The CRSS data show a significant size effect, where smaller cantilevers are apparently stronger. This is very obvious at cantilever widths below ~5 μm but also persists to larger sizes. The size effect is found to be well represented by

$$\tau(w) = \tau_0 + A/w$$

where $\tau(w)$ is the effective CRSS measured for a cantilever of width w, τ_0 is the CRSS for bulk samples and A is a constant representing the strength of the size effect [2]. During bending strains are largest near the built-in end at the top (tensile) and bottom (compressive) regions (twice as large at the bottom due to the orientation of the triangular section). Dislocations tend to be generated in these regions and propagate progressively in towards the neutral axis of the beam where they pile-up. The back-stress from these pile-ups acts against further dislocations being generated and moving to join the pile-up. This effect is seen in discrete dislocation plasticity simulations that inherently capture the size effect [3], but are not present in the length scale independent CP-FEA simulations, where the size effect is manifested instead as an apparent increase in CRSS for smaller cantilever width. This pile-up effect has been confirmed with post-mortem TEM observations of the dislocation pile-ups in Ti alloys [4,5]. Examples of cantilever studies in Ti and Zr alloys will be shown. We will also demonstrate that this approach generates CRSS values which allow the bulk flow stresses of macroscopic polycrystal aggregates to be determined, so enabling micromechanical studies to inform component level performance of industrial alloys [6].

References

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[5] *<c + a> Dislocations in deformed Ti–6Al–4V micro-cantilevers* R Ding, J Gong, AJ Wilkinson, IP Jones, Acta Materialia (2014) **76** 127-134

[6] *<a> prismatic, <a> basal, and <c+a> slip strengths of commercially pure Zr by micro-cantilever tests* J Gong, TB Britton, M Cuddihy, FPE Dunne and AJ Wilkinson (2015), under review